

BU-HEPP-08-02
Mar., 2008

Review of Applications of YFS-Style Resummation in Quantum Field Theory via Monte Carlo Methods[†]

B.F.L. Ward

*Department of Physics,
Baylor University, Waco, Texas, 76798-7316, USA*

Abstract

We review the application of exact, amplitude-based, YFS-style resummation in quantum field theory via Monte Carlo methods.

Invited talk presented at the 2008 Cracow Epiphany Conference
in honor of the 60th birthday of Prof. S. Jadach

[†] Work partly supported by US DOE grant DE-FG02-05ER41399 and by NATO Grant PST.CLG.980342.

1 Preface

It is with great pleasure that I present this review of the application of YFS-style [1] exact, amplitude based resummation via Monte Carlo methods on the occasion of the 60th birthday of Prof. S. Jadach, my friend and collaborator since 1985. In the review, we intend to highlight some of the many pioneering contributions which Prof. Jadach has made to this important subject. We are all grateful to him for all that he has taught us about the subject.

2 Introduction

The theoretical foundation of the subject of this discussion is the pioneering paper by D.R. Yennie, S.C. Frautschi and H. Suura published already in 1961 [1]. In this paper, the exact result for the processes $f_1(p_1) + f_2(p_2) \rightarrow f_3(p_3) + f_4(p_4) + n(\gamma)$ is given as

$$d\sigma_{\text{exp}} = e^{2\alpha\Re B + 2\alpha\tilde{B}} \sum_{n=0}^{\infty} \frac{1}{n!} \int \prod_{j=1}^n \frac{d^3 k_j}{k_j} \int \frac{d^4 y}{(2\pi)^4} e^{iy \cdot (p_1 + p_2 - p_3 - p_4 - \sum k_j) + D} \\ * \tilde{\beta}_n(k_1, \dots, k_n) \frac{d^3 p_3}{p_3^0} \frac{d^3 p_4}{p_4^0} \quad (1)$$

where the hard photon residuals, $\tilde{\beta}_n(k_1, \dots, k_n)$, as defined in Ref. [1], are free of infrared singularities to all orders in α . We use an obvious notation for the 4-momenta $\{p_i\}$ for the scattering charged particles $\{f_i\}$ and the infrared functions B , \tilde{B} , and D are as defined in Ref. [1]. The exactness of (1) is essential for precision theory applications.

The presentation is organized as follows. In the next Sections, we review the applications of (1). We discuss in this connection the period before precision electroweak(EW) physics at LEP/SLC, the era of precision EW physics, the applications of the QCD extension of (1) for precision LHC physics and recent results obtained from applications of the extension of (1) for quantum general relativity. We conclude with some discussion of possible future applications. The Appendix gives an example of uncited impact of our calculations.

3 Applications: Comparative Observations

The original applications [1] of (1) were at the precision of the leading term, the $\tilde{\beta}_0$ -level, in which one retains only the $n = 0$ -term therein. The 4-momentum conservation in (1) is then treated exactly, which necessitates integration over the y -dependent exponential factors therein. This was done in Ref. [1] already, with the result, for example, for initial

state radiation(ISR) in e^+e^- annihilation,

$$d\sigma_{exp} \cong \gamma F_{YFS}(\gamma)(1-z)^{\gamma-1} \sigma_B dz \quad (2)$$

where we have defined $z = s'/s$, $\gamma = \frac{2\alpha}{\pi}(\ln \frac{s}{m^2} - 1)$, and

$$F_{YFS}(\gamma) = \frac{e^{-C\gamma}}{\Gamma(1+\gamma)}. \quad (3)$$

Here, $C = 0.5772\dots$ is Euler's constant and σ_B is the respective Born cross section. Only the leading terms in γ are then retained in this $\bar{\beta}_0$ -level approximation [1]. The accuracy is expected to be in the $\lesssim 10\%$ regime, which is quite adequate for applications in which there were errors on σ_B that could be much larger. It is also important to note that these early applications of (1) were (semi-)analytical in nature.

The LEP1/SLC, LEP2 era marked the application of (1) to precision predictions from quantum field theory via exact Monte Carlo methods. The collaboration in this connection between the author and Staszek (Prof. Jadach) started in the 1985-1986 time frame as a result of a Radiative Corrections Workshop organized at SLAC by Prof. G. Feldman, who at that time was a Spokesman for the MkII Collaboration at the SLC. We were both invited to participate in that workshop and as a result we began discussion of the feasibility to realize the exact result (1) by Monte Carlo methods¹. The key issue, after much successful discussion on other issues, such as our reduction procedure [2], etc., was the realization by Monte Carlo methods of the factor e^D in (1). The pioneering solution was given by Prof. Jadach in Ref. [3]. The title of the paper, "Yennie-Frautschi-Suura Soft Photons in the Monte Carlo Event Generators", underscores how important it was to the Jadach-Ward approach to precision theory for quantum field theory predictions for physical processes: it opened the way to use the exact result (1) via Monte Carlo methods so that arbitrarily precise predictions could be obtained on an event-by-event basis. The solution presented in Ref. [3] is to date the only such solution known and thus is a true testament to the genius of its creator.

With the complete set of ingredients now in place to realize (1), we published in 1988 in Ref. [2] the first realistic MC for precision SLC/LEP1 physics, YFS1, an exact $\mathcal{O}(\alpha)$, YFS-exponentiated multiple photon MC for $e^+e^- \rightarrow f\bar{f} + n(\gamma)$, $f \neq e$. Here, the modifier "YFS" denotes that the exponentiation is the resummation given by (1). As we discuss in Ref. [2], the precision tag for YFS1 in Z physics is $\lesssim 1\%$. This was followed in 1989 with the publication in Ref. [4] of the first realistic exact $\mathcal{O}(\alpha)$, YFS-exponentiated multiple photon MC for $e^+e^- \rightarrow e^+e^- + n(\gamma)$ at low angles, BHLUMI1.0, for Z physics, where the primary applications were precision luminosity predictions. Again, the precision tag is $\lesssim 1\%$.

The large number of Z's at LEP1 (2×10^7 were detected) necessitated per mille level theory precision in order that the theoretical error would not compromise the outstanding

¹ This was a long and technical discussion, some of it done on walks in the Tatra Mountains at a Zakopane Summer School, for example.

experimental error in the attendant tests of the EW and QCD theories. We therefore developed the YFS2 and YFS3 level MC realizations of (1) in Refs. [5, 6], wherein the precision tags are 0.1% for initial state radiation and for the combination of initial state and final state radiation, respectively.

Continuing in this way, working as well with our collaborators M. Melles, W. Placzek, E. Richter-Was, M. Skrzypek, Z. Was and S. Yost, we have developed the following YFS MC event generators, all realizations of (1): KORALZ3.8,4.04 [7] with 0.1% precision tag on 2f production at the Z regime in LEP1/SLC; BHLUMI2.01,2.30,4.04 [8] for the LEP1/SLC luminosity process small angle Bhabha scattering with the final precision tag of 0.061%(0.054%), according as one does not (does) implement the soft pairs effect from either Ref. [9, 10]; and BHWIDE [11] for the large angle Bhabha scattering with precision tag 0.2% at the Z regime at LEP1/SLC.

The advent of LEP2, and its attendant 2×10^5 W pairs, created the need for precision predictions for W-pair productions and decay, the 4f background processes, radiative return Z production as well as the need for reliable 2Z production predictions. We developed [12] the new coherent realization of (1) to treat the Z-radiative return events at high precision by treating the real emission IR singularities at the level of amplitude in complete analogy with the original treatment of the virtual IR singularities by Yennie, Frautschi and Suura in Ref. [1]. We refer to this form of the theory as the CEEX theory. It is realized in the event generator KK MC [13], which gives 0.2% precision on radiative return 2f production at LEP2 energies. In addition, for LEP2 our collaboration developed the MC's YFSWW3 [14] with 0.4% precision on WW production, KoralW(1.02,1.42) [15] with 1.0% precision on the 4f background processes, KoralW1.51 [16], the concurrent KoralW&YFSWW3 MC, with 0.4% on 4f production near the WW regime, and YFSZZ [17] with 2% precision for ZZ production. These are all state-of-the-art results for LEP2 based on the rigorous MC realization of (1) on an event-by-event basis. We also determined [18] the precisions of BHWIDE and BHLUMI at LEP2 as 0.4% and 0.122% respectively. We now present some exemplary results based on these seminal calculations.

3.1 Exemplary Results

The MC KoralZ was a workhorse for LEP1,2 physics. As an example of its many applications, we illustrate with the analysis by the ALEPH Collaboration [19] of their data on mu-pair production from 20 GeV to 136 GeV: We quote from Ref. [19], "In order to study the effect of the experimental cuts, more than 2×10^6 events were produced with full detector simulation, using the DYMU3[8] and KORALZ 4.0 [9] Monte Carlo event generators for the exclusive and inclusive analysis, respectively, at several nominal LEP energies. Radiation of hard photons in the initial and final state is treated at $\mathcal{O}(\alpha)$ by DYMU3 and at $\mathcal{O}(\alpha^2)$ by KORALZ 4.0. In KORALZ the radiation of soft photons is included at all orders by exponentiation." This is one of many examples.

In Fig. 1, we show the summary of the progress on precision EW theory as presented by Gurtu in his review for ICHEP2000 at Osaka [20]. We see in the figure that he shows BHLUMI4.04 as a key element in these improvements which allowed the proper exploitation of the LEP data for precision SM tests.

For BHWIDE, there are also many examples of its seminal role in establishing the precision comparison between the Standard Model EW theory and the LEP data. We show in Fig. 2 the results presented by De Bonis [21] at ICHEP02, where he shows that BHWIDE gives outstanding agreement with the LEP observations of large angle Bhabha scattering².

For YFSWW and KK MC, there are also many examples of their seminal role in precision LEP physics. To illustrate, we use again an example for from Ref. [20] as shown in Fig. 3 which summarizes the progress in theory for 2f and 4f processes at LEP1,2 for ICHEP2000. The MC YFSZZ is also featured in Fig. 3, as it provided state-of-the-art simulations for the Z-pair production data at LEP2. We see then in Figs. 4, 5 that the YFSWW3, along with RacoonWW [22], did indeed establish the proper normalization and simulation of the LEP2 WW pair production as predicted by the 't Hooft-Veltman non-Abelian gauge theory renormalization theory [23] and that YFSZZ did indeed provide state-of-the-art Z-pair production simulation for the LEP2 data.

The Monte Carlo KoralW has played an essential role in the 4f/WW data analysis as well, providing as it did, precision simulation of the background processes for W-pairs as we have indicated. This is illustrated in Fig. 5. What we have illustrated are examples that indicate the broad effect that the Monte Carlo realization of (1) has had on tests of the SM using precision LEP data.

Indeed, these precision calculations, which we need to emphasize employed as well the pioneering EW libraries of Refs. [25] in isolating some of the purely weak exact results in the residuals $\bar{\beta}_n$, have played essential roles in determining the degree of agreement between then SM non-Abelian loop corrections to precision observables and the value of these effects as measured by LEP data. This is illustrated in Fig. 6 as it is presented in Ref. [26] at ICHEP06. The many consequences of the latter comparison, such as its implications for the mass of the still-sought SM Higgs particle – a main objective for discovery at LHC, are illustrated in Fig. 7. The precision comparison between the SM expectations and the LEP data establish the correctness of the 't Hooft-Veltman renormalization theory for non-Abelian gauge theories at the one-loop level and give us confidence that the origin of EW symmetry breaking, as it is represented by the Higgs boson, is within reach of LHC experimentation. In addition, when the precise value of the running $\alpha_s(Q)$ is extracted for the the LEP data and compared with data at lower energies [27], one

²The actual impact of BHWIDE on e^+e^- annihilation discovery physics is clouded by the exchange of e-mails with Drs. Marsiske and MacFarlane shown in the Appendix. Their Babar Collaboration have used the MC extensively as described by Dr. Marsiske but have not referenced this use in their published papers, only in internal notes as he describes. Such notes are not available to the public so we have no idea as to what the actual impact of the calculation really has been.

also obtains experimental proof of the running of the latter coupling as predicted by the asymptotic freedom discovery of Gross, Wilczek [28] and Politzer [29]. The Royal Swedish Academy [30] has emphasized these points in awarding the 1999 Nobel Prize in Physics to Profs. G. 't Hooft and M. Veltman, with the citation "...for elucidating the quantum nature of the electroweak interactions in physics...The theory's predictions verified...large quantities of W and Z have recently been produced under controlled conditions at the LEP accelerator at CERN. Comparisons between measurements and calculations have all the time showed great agreement, thus supporting the theory's predictions...", and the 2004 Nobel Prize in Physics to Profs. D.J. Gross, F. Wilczek and H.D. Politzer, with the citation "...The theory has been tested in great detail, in particular during recent years at the European Laboratory for Particle Physics, CERN, in Geneva...". Prof. Jadach and his collaborators have made via YFS-based MC methods an essential contribution to the realization of the two respectively cited precision studies.

4 QCD and QED \otimes QCD Extension

Already at the start of the preparations for the physics program for the now canceled SSC, we moved our attention to the application of the analog of (1) to the QCD theory in Refs. [31]. This development has resulted in the QCD resummation formula [32], for the processes $f_1(p_1) + f_2(q_1) \rightarrow f_3(p_2) + f_4(q_2) + n(G)$,

$$d\hat{\sigma}_{\text{exp}} = e^{\Sigma_{\text{IR}}(\text{QCD})} \sum_{n=0}^{\infty} \frac{1}{n!} \int \prod_{j=1}^n \frac{d^3 k_j}{k_j} \int \frac{d^4 y}{(2\pi)^4} e^{iy \cdot (p_1 + q_1 - p_2 - q_2 - \sum k_j) + D_{\text{QCD}}} \\ * \tilde{\beta}_n(k_1, \dots, k_n) \frac{d^3 p_2}{p_2^0} \frac{d^3 q_2}{q_2^0} \quad (4)$$

where now the hard gluon residuals $\tilde{\beta}_n(k_1, \dots, k_n)$ are free of all infrared divergences to all orders in $\alpha_s(Q)$. The functions $SUM_{\text{IR}}(\text{QCD})$, D_{QCD} , together with the attendant basic infrared functions $B_{\text{QCD}}^{\text{nl}s}$, $\tilde{B}_{\text{QCD}}^{\text{nl}s}$, $\tilde{S}_{\text{QCD}}^{\text{nl}s}$ are specified in Ref. [32]. Here, Q is the relevant hard scale. We have shown that (4) leads to an independent cross check of the size of threshold resummation effects in $t\bar{t}$ production at FNAL at the 1% level as found in Ref. [33]. More recently, realizing that for LHC physics the EW corrections can be significant in a 1% error budget, we have extended the result (4) to the simultaneous resummation of QED and QCD, QED \otimes QCD resummation [34],

$$d\hat{\sigma}_{\text{exp}} = e^{\text{SUM}_{\text{IR}}(\text{QCED})} \sum_{n,m=0}^{\infty} \frac{1}{n!m!} \int \prod_{j_1=1}^n \frac{d^3 k_{j_1}}{k_{j_1}} \prod_{j_2=1}^m \frac{d^3 k'_{j_2}}{k'_{j_2}} \int \frac{d^4 y}{(2\pi)^4} \\ e^{iy \cdot (p_1 + q_1 - p_2 - q_2 - \sum k_{j_1} - \sum k'_{j_2}) + D_{\text{QCED}}} \\ \tilde{\beta}_{n,m}(k_1, \dots, k_n; k'_1, \dots, k'_m) \frac{d^3 p_2}{p_2^0} \frac{d^3 q_2}{q_2^0}, \quad (5)$$

where the new YFS [1, 2] residuals, defined in Ref. [34], $\tilde{\tilde{\beta}}_{n,m}(k_1, \dots, k_n; k'_1, \dots, k'_m)$, with n hard gluons and m hard photons, represent the successive application of the YFS expansion first for QCD and subsequently for QED. The functions $\text{SUM}_{\text{IR}}(\text{QCED})$, D_{QCED} are determined from their analogs $\text{SUM}_{\text{IR}}(\text{QCD})$, D_{QCD} via the substitutions

$$\begin{aligned} B_{\text{QCD}}^{nls} &\rightarrow B_{\text{QCD}}^{nls} + B_{\text{QED}}^{nls} \equiv B_{\text{QCED}}^{nls}, \\ \tilde{B}_{\text{QCD}}^{nls} &\rightarrow \tilde{B}_{\text{QCD}}^{nls} + \tilde{B}_{\text{QED}}^{nls} \equiv \tilde{B}_{\text{QCED}}^{nls}, \\ \tilde{\tilde{S}}_{\text{QCD}}^{nls} &\rightarrow \tilde{\tilde{S}}_{\text{QCD}}^{nls} + \tilde{\tilde{S}}_{\text{QED}}^{nls} \equiv \tilde{\tilde{S}}_{\text{QCED}}^{nls} \end{aligned} \quad (6)$$

everywhere in expressions for the latter functions given in Refs. [32]. The residuals $\tilde{\tilde{\beta}}_{n,m}(k_1, \dots, k_n; k'_1, \dots, k'_m)$ are free of all infrared singularities. The result in (5) is a representation that is exact and that can therefore be used to make contact with parton shower MC's without double counting or the unnecessary averaging of effects such as the gluon azimuthal angular distribution relative to its parent's momentum direction.

Indeed, from the result (5) and the standard formula for the hadron cross section,

$$d\sigma = \sum_{i,j} \int dx_1 dx_2 F_i(x_1) F_j(x_2) d\hat{\sigma}_{\text{exp}} \quad (7)$$

we have immediately two issues to address: shower/ME matching, which we do preferably by shower-subtracted residuals, $\tilde{\tilde{\beta}}_{m,n} \rightarrow \hat{\tilde{\beta}}_{m,n}$, as presented in Ref. [35], and for MC stability, IR-improved DGLAP-CS theory [36], a new exponentiated scheme for the respective kernels, P_{AB} , reduced cross sections, and parton distributions,

$$\begin{aligned} F_1, \hat{\sigma} &\rightarrow F'_i, \hat{\sigma}' \quad \text{for} \\ P_{qq} &\rightarrow P_{qq}^{\text{exp}} = C_F F_{\text{YFS}}(\gamma_q) e^{\frac{1}{2}\delta_q} \frac{1+z^2}{1-z} (1-z)^{\gamma_q}, \text{ etc.}, \end{aligned} \quad (8)$$

giving the same value for the respective hadron cross section σ , with improved MC stability.

In addition, other technical checks are now open, such as the issue of setting all quark masses m_q to zero in the ISR at $\mathcal{O}(\alpha_s^n)$, $n \geq 2$ due to the theorem in Refs. [37, 38], according to which there is a lack of Bloch-Nordsieck cancellation of IR singularities unless $m_q = 0$. We show in Ref. [39] that the result (4) obviates this theorem.

The matter of an independent cross-check of the standard backward evolution algorithm for the parton shower itself [40] is also under study with the results of Refs. [41, 42]. Staszek's group are actively involved in this development.

There are many more issues which we do not have space to list here: They are all under study. All of the necessary theoretical formalism is at hand – this underscores the need to support exact results for higher order calculations, cross checks, tests, etc., to prove 1% precision for LHC luminosity processes for example. We can not emphasize this too much.

5 Extension to QGR

The exactness of the re-arrangement means that we can apply the same resummation algebra to quantum gravity [43–46]. We find that the scalar propagator for mass m resums in quantum gravity to

$$i\Delta'_F(k)|_{\text{resummed}} = \frac{ie^{B''_g(k)}}{(k^2 - m^2 - \Sigma'_s + i\epsilon)} \quad (9)$$

for $(\Delta = k^2 - m^2)$

$$\begin{aligned} B''_g(k) &= -2i\kappa^2 k^4 \frac{\int d^4\ell}{16\pi^4} \frac{1}{\ell^2 - \lambda^2 + i\epsilon} \\ &\quad \frac{1}{(\ell^2 + 2\ell k + \Delta + i\epsilon)^2} \\ &= \frac{\kappa^2 |k^2|}{8\pi^2} \ln \left(\frac{m^2}{m^2 + |k^2|} \right), \end{aligned} \quad (10)$$

where the latter form holds for the UV regime, so that (9) falls faster than any power of $|k^2|$. An analogous result [43] holds for $m=0$. We also note that, as Σ'_s starts in $\mathcal{O}(\kappa^2)$, we may drop it in calculating one-loop effects. It follows that when the respective analogs of (9) are used, one-loop corrections are finite. In fact, it can be shown that the use of our resummed propagators renders all quantum gravity loops UV finite [43–46]. We have called this representation of the quantum theory of general relativity resummed quantum gravity (RQG). Its phenomenology is under study: we show in Refs. [46] that the final state of Hawking radiation [47] leads to Planck scale cosmic rays, etc.

6 Future

All of the developments extend to higher energy and/or higher precision at lower energies down to 1GeV: at the B-Factor, the KK MC is already in wide use [48]; at the Φ -factories there are cross checks [49] using KK MC with the distributions of the program PHOKHARA [50], etc.

For higher energies in e^+e^- annihilation, YFSWW, KoralW, BHWIDE, BHLUMI and KK MC are all in play. For example, the ILC luminosity requirement [51] is 0.01%. We show in Table 1 what the extension of BHLUMI from version 4.04 to version 5.0 for 0.011% would involve (The references in the table can be found in Ref. [52]). We have already explained in Ref. [52] what this achievement would involve and how long in time it would take, about 3 years. Again, it is all a question of support. It may be needed by 2025-2030?

From 1987 to 2027, what fun it is! And, we all owe a debt of special thanks to Staszek for his seminal role in it.

Appendix: Example of Internal Un-cited Use of BHWIDE

In this appendix we record an email exchange we have had with members of the BaBar Collaboration regarding the un-cited use of BHWIDE. From the exchange, one can see that BHWIDE was used extensively by the collaboration without ever being referenced in whatever published papers were produced with the aid of its use. Even in the paper in the Nucl. Inst. and Methods journal on the detector itself [53], BHWIDE was not referenced for the simulation of wide angle Bhabha's: was some other calculation used? We will never know.

==E-mail: Drs. Marsiske and MacFarlane(Spokesman) of BaBar and the author ==

—Original Message—

From: Ward, B.F.L.

Sent: Tuesday, February 01, 2005 7:43 AM

To: 'dbmacf@slac.stanford.edu'

Subject: RE: RE: BHWIDE

Hello David,

Thanks again in advance.

Best regards,

Bennie

Bennie F.L. Ward,

Distinguished Professor and Chairman,

Department of Physics,

Baylor University,

P.O. Box 97316

Waco, TX 76798-7316

Tel. 254-710-4878, Fax 254-710-3878

—Original Message—

From: David B. MacFarlane [mailto:dbmacf@slac.stanford.edu]

Sent: Monday, January 31, 2005 11:29 PM

To: Ward, B.F.L.; Staszek.Jadach@cern.ch; Wieslaw.Placzek@cern.ch

Subject: RE: RE: BHWIDE

Bernie:

Thanks for bringing this to my attention. I will have to look into the matter, which will take a little time, but I hope to get back to you by week's end.

Regards,

David

> —Original Message—

> From: Ward, B.F.L. [mailto:BFL_Ward@baylor.edu]

> Sent: Monday, January 31, 2005 10:58 AM

> To: dbmacf@slac.stanford.edu; Staszek.Jadach@cern.ch;

> Wieslaw.Placzek@cern.ch

> Subject: FW: RE: BHWIDE

>

> Hello David,

> As you can see from(sic) my communications with Helmut Marsiske below,

> our calculation BHWIDE, which realizes YFS exponentiated exact

> O(alpha) multiple photon radiative effects on an event-by-event

> basis by MC methods, was introduced into BaBar by Helmut with our

> assistance several years ago.

> He explains below that the program " BHWIDE has since been used

> *extensively* at BABAR and is

> *crucial* for our physics output: it is *the* generator to create MC

> samples of (mostly) non-radiative as well as radiative Bhabhas, and to

> calculate the necessary cross sections and efficiencies. The

> non-radiative Bhabhas are used for our luminosity measurement and for

> the single-crystal calibration of the electromagnetic calorimeter. The

> radiative Bhabhas are used for our cluster energy calibration and for

> E/p studies in connection with electron identification.

> BHWIDE has been referenced (i.e., Phys. Lett. B 390 (1997) 298) in numerous

internal

> documents dealing with the above-mentioned areas of luminosity,
> calibration, and PID. I'm not sure, though, whether it has
> made it into any of our journal publications."
> According to the latest SPIRES data that I have, the program has
> never been referenced by BaBar's many published papers. This is very
> hard on its authors for the obvious reasons: promotions,
> funding awards, etc., in our field, as you well > know as a Collaboration Spokesman,
are

> all ultimately very much dependent on ones citations, especially
> citations by a flagship experiment such as yours.
> Thus, I am writing to ask you why a calculation which has apparently
> been very helpful in your
> physics analysis has never been cited as having played any such role
> therein in the published
> literature? Mentioning BHWIDE in your private Collaboration notes as
> Helmut indiactes(sic) does not really give its authors their proper credit,
> as these notes are not read by the general peer-reviewing public.
> Thanks in advance.
> Best regards,
> Bennie > Bennie F.L. Ward,
> Distinguished Professor and Chairman,
> Department of Physics,
> Baylor University,
> P.O. Box 97316
> Waco, TX 76798-7316
> Tel. 254-710-4878, Fax 254-710-3878

Date: Mon, 22 Apr 2002 14:23:51 -0400

From: bflward <bflward@utk.edu>

To: Stanislaw.Jadach@cern.ch, Wiesiek.Placzek@cern.ch

Cc: bflward@utk.edu

Subject: FWD: RE: BHWIDE

Hello Staszek and Wiesiek,

He says they are going to do better? We will see.

Thanks.

Best regards,

Bennie

>===== Original Message From Helmut Marsiske

><marsiske@SLAC.Stanford.EDU>

=====

Bennie-

of course there is no policy in BABAR against referencing your BHWIDE, or any other, paper, and as I said: it has been referenced in internal notes. The fact that it wasn't mentioned in the NIM detector paper must have been a plain oversight. Sorry for that. We should try to do better in future papers...

-H-

— —

— Dr. Helmut Marsiske Stanford Linear Accelerator Center —

— Stanford University —

— SLAC, Mail Stop 95 E-mail: MARSISKE@SLAC.Stanford.edu —

— 2575 Sand Hill Road Phone: 650-926-4333 —

— Menlo Park, CA 94025 Fax: 650-926-2657 —

— USA URL: www.slac.stanford.edu/~marsiske —

— —

On Wed, 17 Apr 2002, bflward wrote:

> Hello Helmut,

> It is great to hear that BHWIDE has been useful to BaBar. What

> would really help us is the referencing of the program >when it is used in your
 > preprints and publications, if this is possible – at LEP, it is
 > routinely done and we have 84 citations in LEP publications. We seem
 > to have none in BaBar's?
 > For example, in your paper on the BaBar detector, hep-ex/0105044, on
 > page 10, you say you compare with the MC generator but you do not
 > reference which generator it is. If that was BHWIDE, then it would
 > really have helped us with our funding agencies, scientific
 > evaluations, etc. if you could have given us that reference in the
 > paper. Or, is there a policy in BaBar against this?
 > Thanks in advance.
 > Best regards,
 > Staszek Jadach, Wiesiek Placzek and Bennie
 > —Original Message—
 > >===== Original Message From Helmut Marsiske
 > ><marsiske@SLAC.Stanford.EDU>
 > =====
 > Hi Bennie,
 >
 > indeed, BHWIDE has since been used *extensively* at BABAR and is
 > *crucial* for our physics output: it is *the* generator to create MC
 > samples of (mostly) non-radiative as well as radiative Bhabhas, and to
 > calculate the necessary cross sections and efficiencies. The
 > non-radiative Bhabhas are used for our luminosity measurement and for
 > the single-crystal calibration of the electromagnetic calorimeter. The
 > radiative Bhabhas are used for our cluster energy calibration and for
 > E/p studies in connection with electron identification. BHWIDE has
 > been referenced (i.e., Phys. Lett. B 390 (1997) 298) in numerous
 > *internal* documents dealing with the above-mentioned areas of

> luminosity, calibration, and PID. I'm not sure, though, whether it has
> made it into any of our journal publications.
>
> Hope this helps,
>
> Helmut
>
> _____
> _____
> —
> —
> —
> — Dr. Helmut Marsiske Stanford Linear Accelerator
> Center —
> — Stanford University
> —
> — SLAC, Mail Stop 95 E-mail:
> MARSISKE@SLAC.Stanford.edu —
> — 2575 Sand Hill Road Phone: 650-926-4333
> —
> — Menlo Park, CA 94025 Fax: 650-926-2657
> —
> — USA URL:
> www.slac.stanford.edu/ marsiske —
> —
> _____
>
> On Mon, 8 Apr 2002, bflward wrote:
>
> > Hello Helmut,

> > If I recall correctly, you introduced BHWIDE into the BaBar
> > software? Has it actually been used for any analysis of wide angle
> > Bhabha's, etc., yet, and, if so, was that use referenced
> anywhere in Babar preprints or publications?
> I am having to explain my existence
> > to my program manager for DoE (i.e., he is cutting my
> grant) and any information like this would be very helpful, indeed.
> > Thanks in advance.
> > Best regards,
> > Bennie

References

- [1] D. R. Yennie, S. C. Frautschi, and H. Suura, *Ann. Phys.* **13** (1961) 379; see also K. T. Mahanthappa, *Phys. Rev.* **126** (1962) 329, for a related analysis.
- [2] S. Jadach and B.F.L. Ward, *Phys. Rev.* **D38** (1988) 2897.
- [3] S. Jadach, “Yennie-Frautschi-Suura Soft Photons in Monte Carlo Event Generators”, preprint MPI-PAE/PTh 8/87, unpublished.
- [4] S. Jadach and B.F.L. Ward, *Phys. Rev.* **D40** (1989) 3582.
- [5] S. Jadach and B.F.L. Ward, *Comput. Phys. Commun.* **56** (1990) 351.
- [6] S. Jadach and B.F.L. Ward, *Phys. Lett.* **B274** (1992) 470.
- [7] S. Jadach, B.F.L. Ward and Z. Was, *Comput. Phys. Commun.* **66** (1991) 276; *ibid.* **79** (1994) 503; *ibid.* **124** (2000) 233.
- [8] S. Jadach *et al.*, *Comput. Phys. Commun.* **70** (1992) 305; *ibid.* **102** (1997) 229.
- [9] S. Jadach, M. Skrzypek and B.F.L. Ward, *Phys. Rev.* **D55** (1997) 1206.
- [10] G. Montagna *et al.*, *Nucl. Phys.* **B547** (1999) 39; *Phys. Lett.* **B459** (1999) 649.
- [11] S. Jadach, W. Placzek and B.F.L. Ward, *Phys. Lett.* **B390** (1997) 298.
- [12] S. Jadach, B.F.L. Ward and Z. Was, *Phys. Lett.* **B449** (1999) 97; *Phys. Rev.* **D63** (2001) 113009.
- [13] S. Jadach, B.F.L. Ward and Z. Was, *Comput. Phys. Commun.* **130** (2000) 260.
- [14] S. Jadach *et al.*, *Phys. Lett.* **B417** (1998) 326; *Comput. Phys. Commun.* **140** (2001) 432.
- [15] M. Skrzypek *et al.*, *Comput. Phys. Commun.* **94** (1996) 216; S. Jadach *et al.*, *Comput. Phys. Commun.* **119** (1999) 272.
- [16] S. Jadach *et al.*, *Comput. Phys. Commun.* **140** (2001) 475.
- [17] S. Jadach *et al.*, *Phys. Rev.* **D56** (1997) 6939.
- [18] S. Jadach *et al.*, in *Geneva 1995, Physics at LEP2, vol. 2*, p. 229.
- [19] R. Barate *et al.*, *Phys. Lett.* **B399** (1997) 329.
- [20] A. Gurtu, in *Osaka 2000, High energy physics, vol. 1*, p. 107.
- [21] I. De Bonis, in *Amsterdam 2002, ICHEP*, p. 182.

- [22] A. Denner *et al.*, Phys. Lett. **B475** (2000) 127; Nucl. Phys. **B587** (2000) 67.
- [23] G. 't Hooft and M. Veltman, Nucl. Phys. **B44**,189 (1972) and **B50**, 318 (1972); G. 't Hooft, *ibid.* **B35**, 167 (1971); M. Veltman, *ibid.* **B7**, 637 (1968).
- [24] P. Azzurri, in *Moscow 2006, ICHEP, vol. 1*, p.693.
- [25] A. Arbuzov *et al.*, Comput. Phys. Commun. **174** (2006) 728; D. Yu. Bardin *et al.*, Comput. Phys. Commun. **133** (2001) 229; W. F. L. Hollik, Fortsch. Phys. **38** (1990) 165; D. C. Kennedy, B. W. Lynn and R. G. Stuart, Nucl. Phys. **B321** (1989) 83; R. G. Stuart, RAL-T-008, 1985; J. Fleischer, F. Jegerlehner and M. Zralek, Z. Phys. **C42** (1989) 409; J. Fleischer, K. Kolodziej and F. Jegerlehner, Phys. Rev. **D47** (1993) 830; *ibid.* **D49** (1994) 2174; J. Fleischer *et al.*, Comput. Phys. Commun. **85** (1995) 29.
- [26] D. R. Wood, in *Moscow 2006, ICHEP, vol. 1*, p. 113.
- [27] S. Bethke, Nucl. Phys. Proc. Suppl. **135** (2004) 345, and references therein.
- [28] D. J. Gross and F. Wilczek, Phys. Rev. Lett. **30** (1973) 1343; see also , for example, F. Wilczek, in *Proc. 16th International Symposium on Lepton and Photon Interactions, Ithaca, 1993*, eds. P. Drell and D.L. Rubin (AIP, NY, 1994) p. 593, and references therein.
- [29] H. David Politzer, *ibid.***30** (1973) 1346.
- [30] See *Nobel Prize in Physics press releases*, Royal Swedish Academy, 1999; *ibid.*, 2004.
- [31] D. DeLaney *et al.*,Phys. Rev. **D52** (1995) 108; Phys. Lett. **B342** (1995) 239; Phys. Rev. **D66** (2002) 019903(E).
- [32] B.F.L. Ward and S. Jadach, *Acta Phys.Polon.* **B33** (2002) 1543; in *Proc. ICHEP2002*, ed. S. Bentvelsen *et al.*,(North Holland, Amsterdam, 2003) p. 275 ; B.F.L. Ward and S. Jadach, *Mod. Phys. Lett.***A14** (1999) 491 ; D. DeLaney *et al.*, *Mod. Phys. Lett.* **A12** (1997) 2425;
- [33] S. Catani *et al.*, Phys. Lett. **B378** (1996) 329.
- [34] C. Glosser, S. Jadach, B.F.L. Ward and S.A. Yost,*Mod. Phys. Lett.***A 19**(2004) 2113; B.F.L. Ward, C. Glosser, S. Jadach and S.A. Yost, in *Proc. DPF 2004*, Int. J. Mod. Phys. **A20** (2005) 3735; in *Proc. ICHEP04, vol. 1*, eds. H. Chen et al.,(World. Sci. Publ. Co., Singapore, 2005) p. 588; B.F.L. Ward and S. Yost, preprint BU-HEPP-05-05, and references therein.
- [35] B.F.L. Ward and S. Yost, preprint BU-HEPP-05-05, in *Proc. HERA-LHC Workshop*, CERN-2005-014; in *Moscow 2006, ICHEP, vol. 1*, p. 505; *Acta Phys. Polon.* **B38** (2007) 2395; arXiv:0802.0724, in press at *Proc. RADCOR07*, 2008.

- [36] B.F.L. Ward, arXiv:0707.3424, Ann. Phys., in press, DOI:10.1016/j.aop.2007.11.010; hep-ph/0508140.
- [37] C. Di’Lieto, S. Gendron, I.G. Halliday, and C.T. Sachradja, Nucl. Phys.**B183**(1981) 223; R. Doria, J. Frenkel and J.C. Taylor, *ibid.***B168**(1980) 93, and references therein.
- [38] S. Catani, M. Ciafaloni and G. Marchesini, Nucl. Phys.**B264**(1986) 588; S. Catani, Z. Phys. **C37** (1988) 357, and references therein.
- [39] B.F.L. Ward, arXiv:0707.2101.
- [40] T. Sjostrand, Phys. Lett. **157B** (1985) 321.
- [41] P. Stevens *et al.*, Acta Phys. Pol. **B38** (2007) 2379 and references therein.
- [42] S. Schumann and F. Krauss, arXiv:0709.1027; Z. Nagy and D. E. Soper, hep-ph/0601021; P. Golonka and Z. Was, hep-ph/0508015; C.M.C. Calame, Phys. Lett. **B520** (2001) 16, and references therein.
- [43] B.F.L. Ward, Mod. Phys. Lett. **A17** (2002) 2371.
- [44] B.F.L. Ward, Mod. Phys. Lett. **A19** (2004) 143.
- [45] B.F.L. Ward, J. Cos. Astropart. Phys.**0402** (2004) 011.
- [46] B.F.L. Ward, hep-ph/0503189,0502104, hep-ph/0411050, 0411049,0410273; Acta Phys. Polon. **B37** (2006) 1967; hep-ph/0607198; hep-ph/0610232, in *Moscow 2006, ICHEP, vol. 2* p. 1233, and references therein.
- [47] S. Hawking, Nature (London) **248** (1974) 30; Commun. Math. Phys. **43** (1975) 199.
- [48] See for example Y. Nishio *et al.*, arXiv:0801.2475.
- [49] S. Jadach, B. F. L. Ward and S. A. Yost, Phys. Rev. D **73** (2006) 073001 and referneces therein.
- [50] H. Czyz *et al.*, Eur. Phys. J. **C39** (2005) 411, and references therein.
- [51] J.E. Brau, “R&D for Future Detectors”, talk, ICHEP04, Beijing, slide 37.
- [52] B.F.L. Ward, Renewal Proposal to US DOE Office of High Energy Physics, Nov., 2007, for Task A, contract DE-FG02-05ER41399.
- [53] B. Aubert *et al.*, Nucl. Instrum. Meth. **A479** (2002) 1.

35

Extraction of Z parameters

Heroic efforts to Reduce SYSTEMATIC ERRORS

- **Experiments: Detector Upgrades (LUMI)**
- **LEP machine/energy groups: Model incorporating environmental effects - Earth Tide effects, Leakage currents due to passing trains**
- **Theoretical improvements:**
 - ZFITTER 6.23 (D.Bardin et al)
 - TOPAZ0 4.4 (G.Passarino et al)
 - ALIBABA (W. Beenaker et al), $e^+e^- \rightarrow e^+e^-(\gamma)$
 - BHLUMI 4.04 (S.Jadach et al)
 - Contributions from G.Degrassi et al, G.Montagna et al, B. Kniehl, J.Kuhn et al, F.A.Berends et al, B.Ward, Z.Was, ...

Overall theoretical errors very small

$\Delta M_Z : \pm 0.3 \text{ MeV}; \Delta \Gamma_Z : \pm 0.2 \text{ MeV}; \Delta \sigma_h^0 : \pm 0.02\%$
(different options for photonic and fermion pair radiation)

$\Delta R_\ell : \pm 0.004$ (ZFITTER-TOPAZ0 differences in parametrising observables)

Precision Tests of the EW Gauge Theory, ICHEP2000, Osaka. A. Gurtu

Figure 1: Summary of EW theory progress on Z physics as presented by Gurtu [20] in ICHEP2000.

similar fitting procedure



Good agreement with the SM expectations (BHWIDE)

Di fermion production at LEP2

26th July 2002

9



19

Theoretical Developments

To match

- superb performance of machines (LEP,SLC,Tevatron,...),
- excellent high resolution detectors, experimental analyses,
- need matching **THEORETICAL** predictions

4-fermion processes
(see LEP2MC workshop proceedings hep-ph/0005309)

- $-\sigma(W^+W^-)$ to 0.4%: (Use of Double-Pole Approx - valid much above threshold) (RacoonWW, YFSWW3)
- $-\sigma(1-W)$ to 4-5% (Use of Fermion Loop Scheme) (WPHACT, grc4f)
- $-\sigma(ZZ)$ to 2% (YFSZZ, ZZTO)
- GENTLE v2.10 now corrects for overestimated Coulomb correction; agrees well with RacoonWW; still $\sim 0.75\%$ ISR related uncertainty

2-fermion processes
ZFITTER, KKMC give
better than 0.2% accuracy in $\sigma(\text{tot})$, of hadrons, leptons
0.2-0.4% on A_{FB}

KKMC 1st MC for LEP, LC, μ -colliders, τ , b factories

Overall Excellent $\text{EXPT} \Longleftrightarrow \text{THEORY}$ Match

Precision Tests of the EW Gauge Theory, ICHEP2000, Osaka.

A. Gurtu

Figure 3: Comparison of YFSWW3 and RacoonWW with precision LEP2 data as presented in Ref. [20] at ICHEP2000.

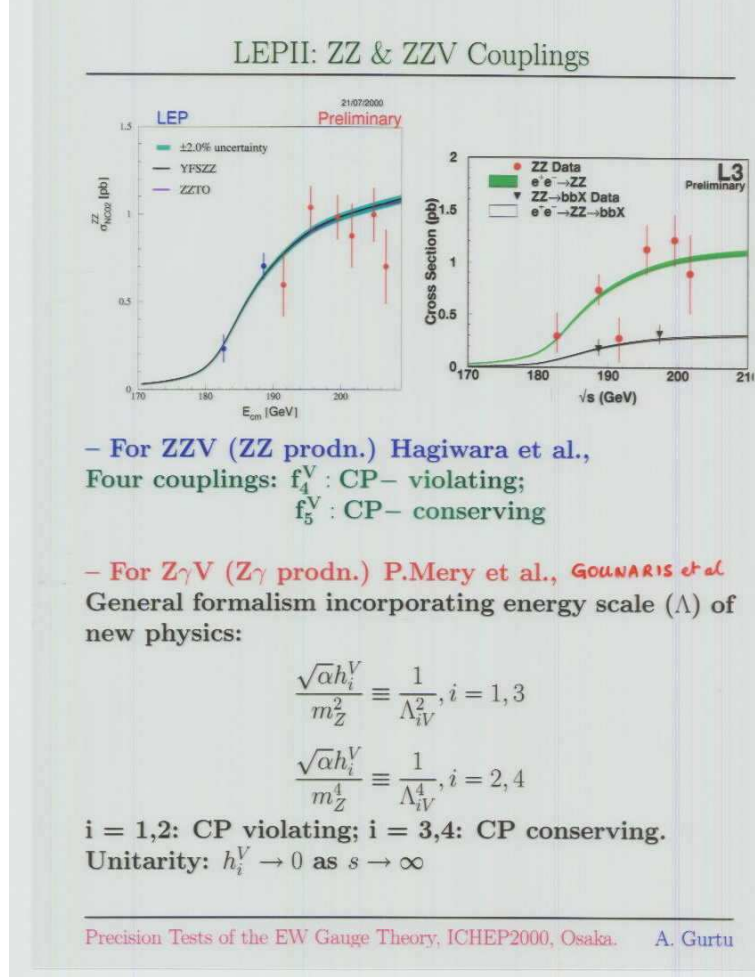


Figure 4: Comparison of YFSZZ with LEP2 Z-pair production data as presented in Ref. [20] at ICHEP2000.

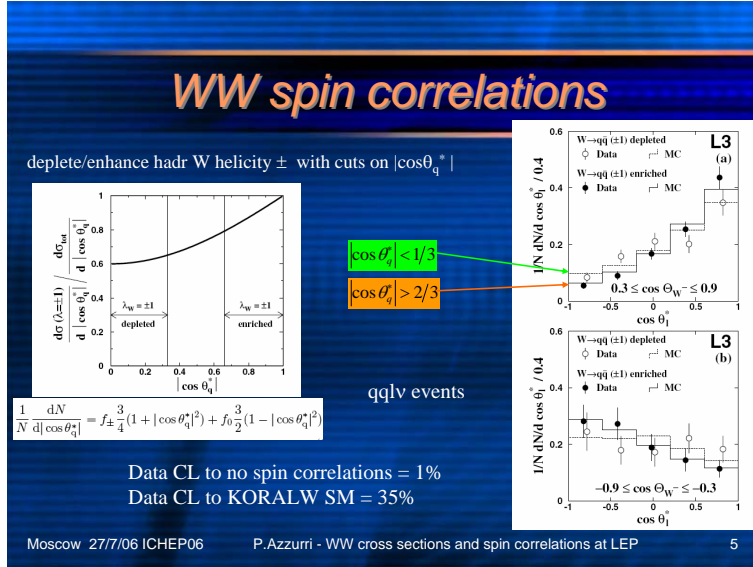


Figure 5: Comparison of KoralW with LEP2 WW/4f spin correlation production data as presented in Ref. [24] at ICHEP2006.

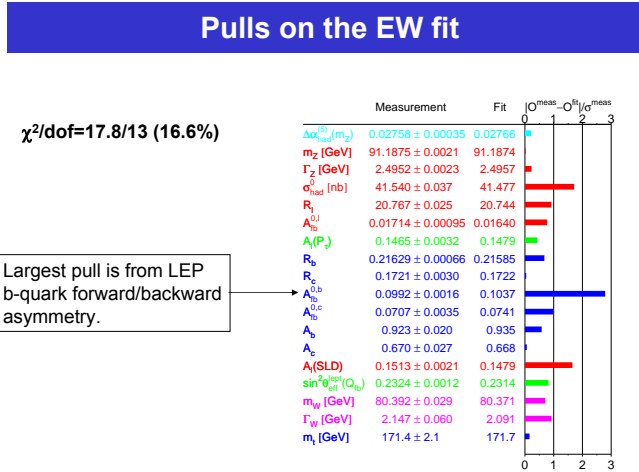
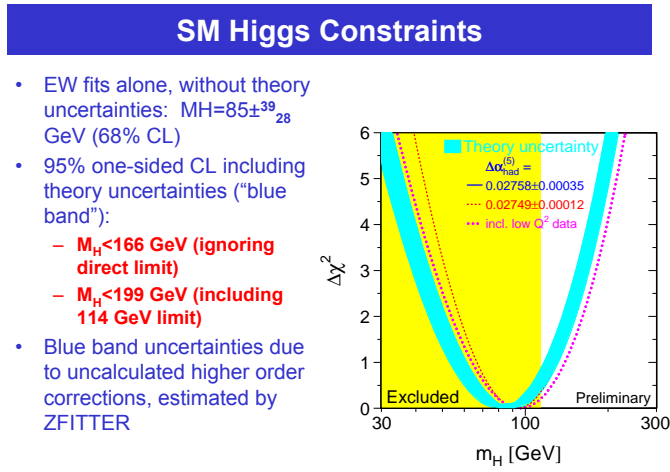


Figure 6: Comparison of precision EW data with the SM theory as presented in Ref. [26] at ICHEP2006.



8/1/2006

Darien Wood, ICHEP06, "Electroweak Physics"

43

Figure 7: Implications for the mass of the SM Higgs particle from the SM EW fit to precision LEP data as presented in Ref. [26] at ICHEP2006.

| | LEP1 | | LEP2 | ILC |
|--|-----------------------------|---------|--------------------------------|---------|
| Type of correction/error | Past ^[BW22,BW23] | Present | Present ^[BW16,BW17] | Future |
| (a) Missing photonic $\mathcal{O}(\alpha^2)$ ^[BW24] | 0.10% | 0.027% | 0.04% | 0.001% |
| (b) Missing photonic $\mathcal{O}(\alpha^3)$ ^[BW25] | 0.015% | 0.015% | 0.03% | 0.0011% |
| (c) Vacuum polarization ^[BW26,BW27] | 0.04% | 0.04% | 0.10% | 0.0096% |
| (d) Light pairs ^[BW19,BW20] | 0.03% | 0.03% | 0.05% | 0.005% |
| (e) Z-exchange ^[BW28] | 0.015% | 0.015% | 0.0% | 0.001% |
| Total | 0.11% | 0.061% | 0.122% | 0.011% |

Table 1: Summary of the total (physical+technical) theoretical uncertainty for a typical calorimetric detector. For LEP1, the above estimate is valid for the angular range within $1^\circ - 3^\circ$, for LEP2 it covers energies up to 176 GeV, and angular range within $1^\circ - 3^\circ$ and $3^\circ - 6^\circ$, and for ILC the projection is for $3^\circ - 6^\circ$ and energies up to 3 TeV.